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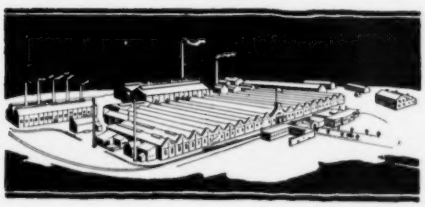

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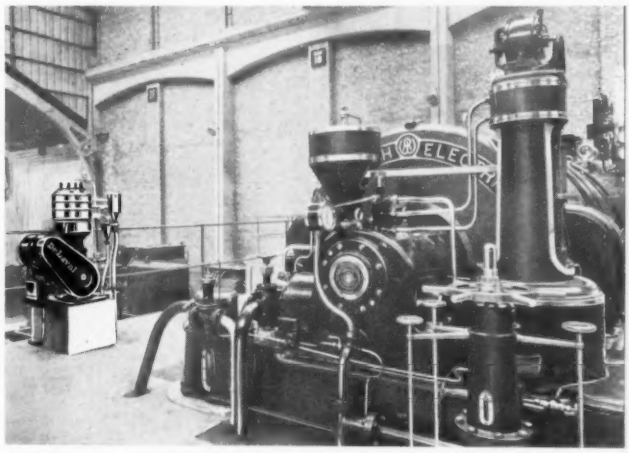

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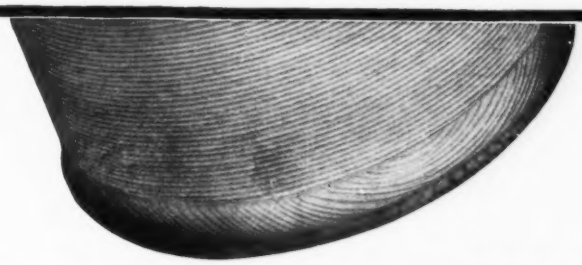

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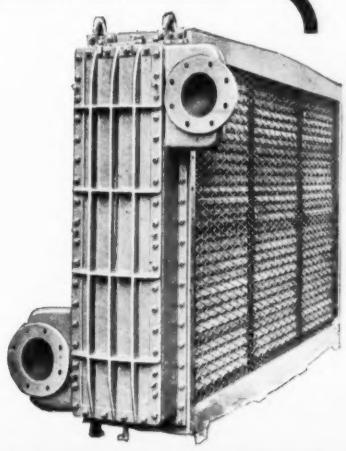

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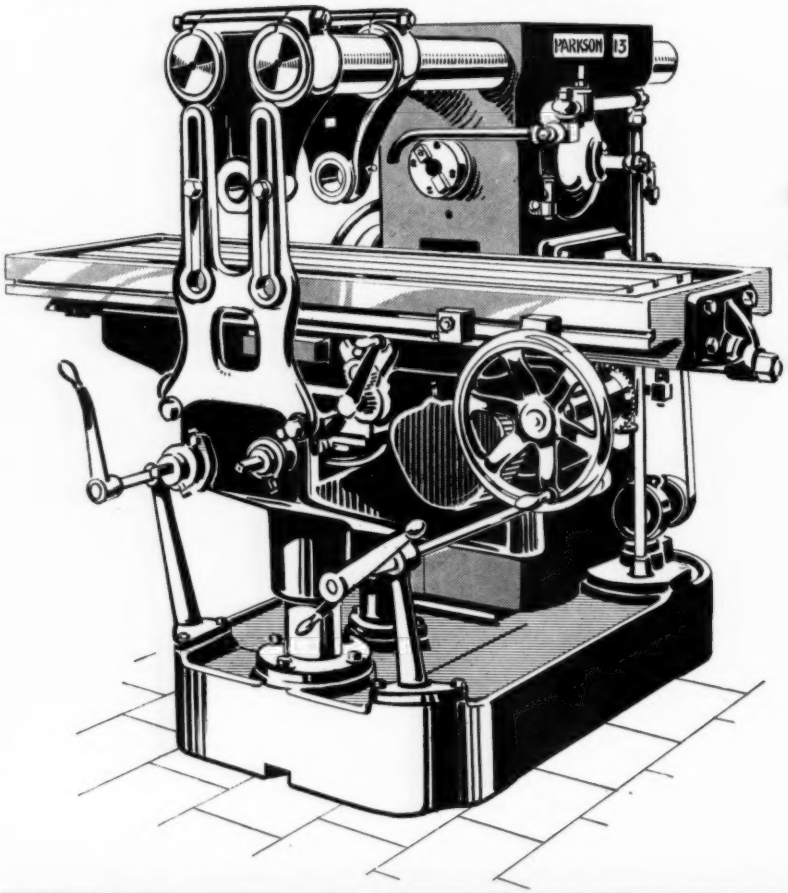

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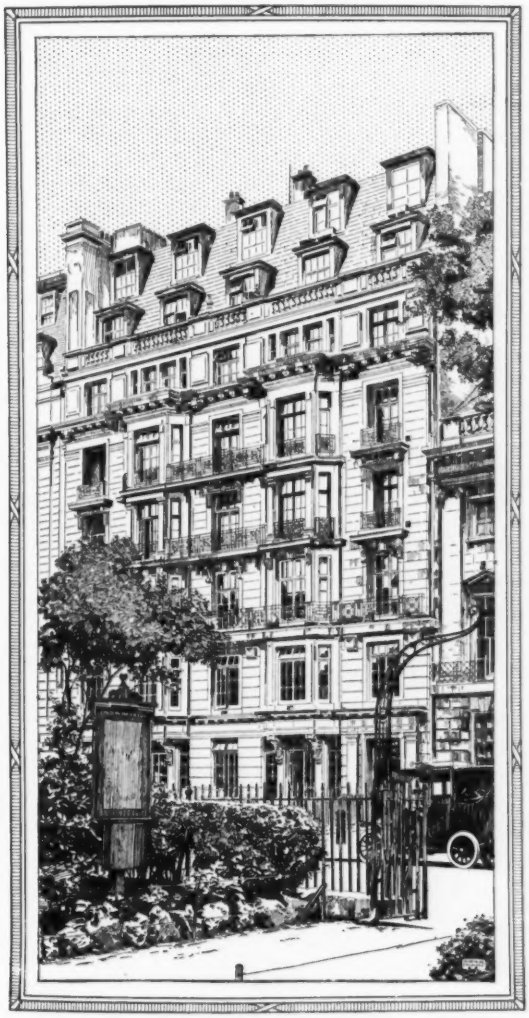

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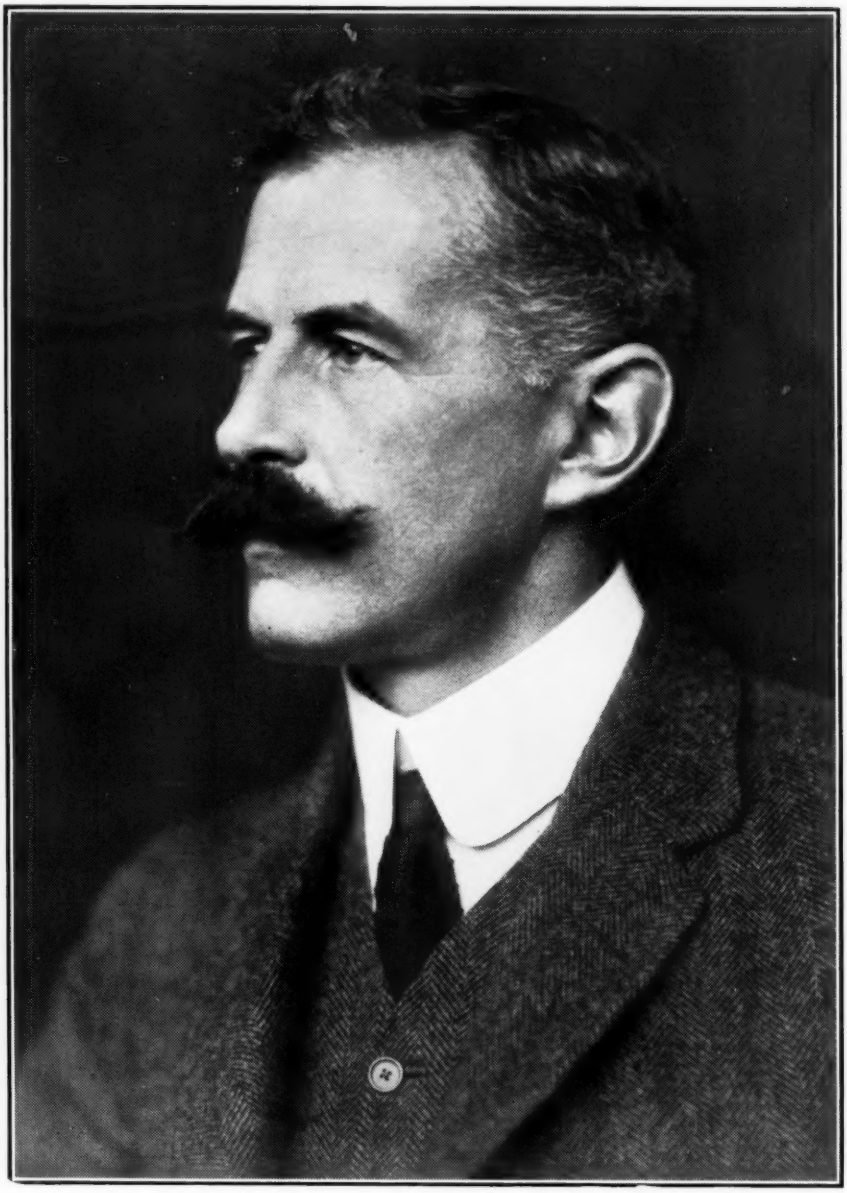

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W. L. Hichens.

The English Electric Journal

Vol. IV. No. 1. SEPTEMBER, 1927. One Shilling.

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THE COMPANY'S NEW CHAIRMAN.

Mr. William Lionel Hichens, who has been appointed chairman of The English Electric Company Limited, in succession to Mr. P. J. Pybus, was born in 1874 and educated at Winchester and New College, Oxford. Since 1910 he has been chairman of Cammell Laird and Co., Limited, of Sheffield, Birkenhead and Nottingham, which firm also holds the ordinary shares of the Midland Railway Carriage and Wagon Co., Limited, of Birmingham; while other industrial undertakings over which he presides as chairman include the Leeds Forge Co., Limited, the Newlay Wheel Co., Limited, and the Tranmere Bay Development Co., Limited. In addition, he is a director of the London Midland and Scottish Railway, the Dundalk, Newry and Greenore Railway, and the Power and Traction Finance Co., Limited. Mr. Hichens, who is a member of the Carnegie Trust, was at one time a member of the Egyptian Ministry of Finance, while other high offices which he has held include that of Colonial Treasurer of the Transvaal and Treasurer of the Inter-Colonial Council of the Transvaal and Orange River Colony. In 1907 he went to India as a member of the Royal Commission on Decentralisation, and in 1909 was chairman of a board of inquiry into the Public Service of Southern Rhodesia. In 1915 he visited Canada on behalf of the Ministry of Munitions, while he has also been a member of several reconstruction committees and of the Advisory Council to the Ministry of Munitions on the Disposal of Surplus Government Property. Other bodies to which he has been elected include

the Advisory Committee to the Department of Overseas Trade, the Industrial Fatigue Research Board, and the Consultative Council of the Import and Export Restrictions Department of the Board of Trade. Mr. Hichens has at all times been considerably interested in the labour problem and is the author of treatises relating to the functions of the Government in relation to industry, the new spirit in industrial relations and the problems of modern industry. He has also delivered lectures on the labour question before many of the learned societies.

EDITORIAL.

For over twenty years the Company's Stafford Works have been actively engaged in the manufacture of switchgear, and during this period have dealt with all classes of gear from small panels for the control of single motors, to the complete equipment for the control of the largest Power Stations. The Switchgear Shops in the Works have been greatly extended in recent years and now form one of the main sections of the Works.

From the commencement the Works have taken a prominent part in all the successive developments in switchgear manufacture and design that have proceeded *pari passu* with the increased outputs and voltages of electric generating plant, and perhaps the most notable of recent developments has been in connection with switchgear of the outdoor type. The outdoor type originated in the extended use of pressures of 100,000 volts and more, as it then became manifest that the large clearances required round the busbars and connections necessitated unduly spacious and expensive buildings. The experience gained with this extra-high-tension gear, subject as it was to all the vicissitudes of weather, then led to the use of the outdoor type of gear for lower voltages. In this case also, the saving in buildings was shown to be considerable, and, further, it was found that the outdoor arrangement gave much greater flexibility in the way of alterations and extensions when these were required. The kiosk type of outdoor equipment has also greatly extended its scope, and has shown itself to be a cheap and eminently satisfactory arrangement for the housing of transformers for local distribution, together with the switchgear that controls them.

The use of outdoor switchgear has been one of the most remarkable developments in recent times, and we believe that the article on this subject that we publish in this issue of the Journal will be read with general interest.

A further article deals with the latest forms of current and potential transformers manufactured by the Company. On reading this article it will be realised that a large number of standard types are necessary to meet the varied requirements of the different classes of plant, and, as is the case with so many lines of manufacture, a high degree of specialisation is necessary if the best results are to be obtained.

Switchgear Manufacture at Stafford Works.

FIG. 1. VIEW IN THE DETAIL ASSEMBLY SHOP.

The Stafford Works of the Company form a well known landmark on the main line of the London, Midland & Scottish Railway, and are situated on a site of about 56 acres on the outskirts of the town, which, it will be recalled, lies in a rural district approximately midway between the "Black Country" and the "Potteries." The Workshops, which cover an area of 7½ acres, are divided into two main sections that radiate from the testing and the dispatching departments, which are thus common to both. One section is occupied in the production of heavy electrical machinery and transformers, and the other in the manufacture of switchgear.

The Switchgear Department has been considerably extended during recent years, and now has a floor space of about 100,000 sq. ft. devoted solely to the designing, fabrication and assembly of this class of apparatus; this area is exclusive of the Foundry, Pattern Shop, Smithies, Tool Shop, Testing and Despatch Departments, which serve the whole works. Switchgear has been produced here for over twenty years, and the latest extensions give facilities for the largest sizes of apparatus required for the control of modern super power stations and extra-high-tension transmission lines. It is interesting to record that some of the earliest installations are still in operation and giving full satisfaction, in spite of the fact that the systems on which they are used have grown far beyond the rated capacity of the apparatus, and, in particular, the Oil Circuit-Breakers of the Company have an unexcelled record for reliable performance under the most severe emergency conditions.

The general layout of the Works is well arranged for the economical routing of the processes, from the raw material to the assembly and dispatch of the finished apparatus. In the eastern block of buildings there are a number of bays with the Main Stores running transversely across them at the northern end. On the extreme east is the Machine Shop with

the Special Finish Annexe at one end; parallel to this are the Detail Assembly and Small Switchboard Assembly Shops. On the western side is a larger and higher block which forms the Large Assembly Shop leading at its northern end into the Dispatch Department.

In the Detail Assembly Shop, Fig. 1, are assembled complete apparatus of the smaller kinds and the main components of larger apparatus. To facilitate this work there is a calibration, flashing and general testing section attached to the shop so that individual apparatus can be adjusted and checked before final assembly or transference to the finished goods store which is adjacent.

The Large Assembly Shop, illustrated in Figs. 2 and 4, is a well-lighted bay 370 ft. long and 23 ft. high to the crane rail, and in it are erected slate switchboards, steel structures, oil breakers and similar large control gear.

The Special Finish Annexe is a busy and important auxiliary to the main processes, and is equipped for plating with tin, copper, zinc, silver and nickel, for spray coating and for stove enamelling. The newest methods of treatment are continually being investigated, and, recently, experimental work has been carried out on plating with chromium and cadmium. Finish plays a highly important part in switchgear of all kinds, for while protection from corrosion, adaptability to cleanliness, and good appearance are valuable features, there are also certain problems arising from the Peltier effect which can be largely diminished or eliminated by suitably plating contact surfaces which for one reason or another are of different metals. Considerable use is now made of cellulose paint in various colours for spray coating the interior of relay casings, etc.; it is quick drying, durable and of good appearance.

Fig. 2. View in the Large Assembly Shop.

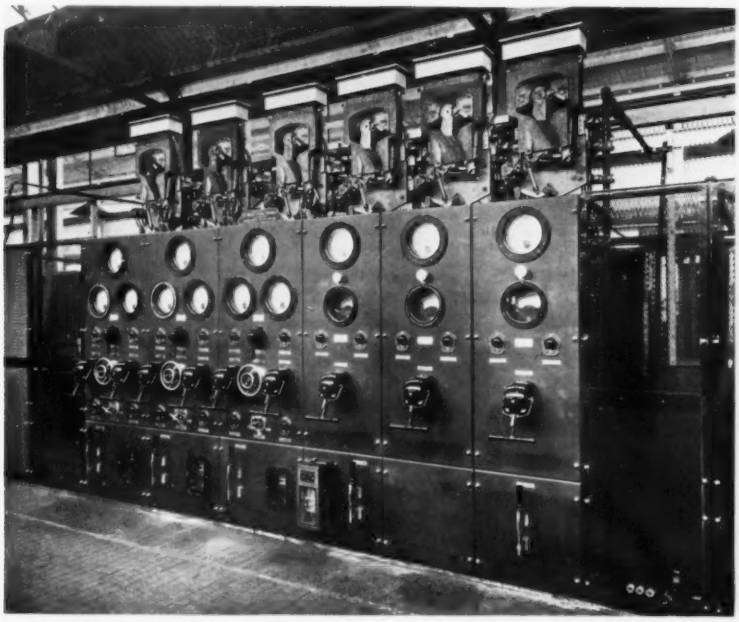


FIG 3. 1500-VOLT, D.C. SWITCHBOARD FOR A SOUTH AMERICAN RAILWAY SYSTEM.

FIG. 4. THE DISPATCH END OF THE LARGE ASSEMBLY SHOP.

FIG. 5. 20,500-VOLT CELLWORK AT EALING.

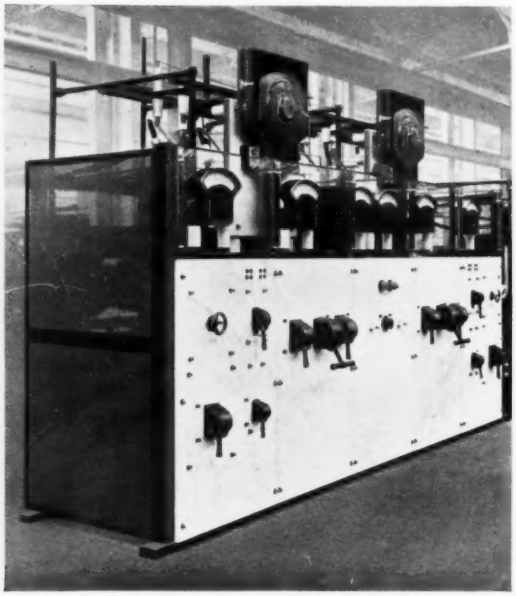


FIG. 6. 10,000-VOLT D.C. SWITCHBOARD FOR A MARCONI WIRELESS INSTALLATION.

FIG. 7. SIXTY 2,600 VOLT DISTRIBUTION CUBICLES AT EALING.

Testing of complete apparatus, where possible in conjunction with the plant it has to control, is carried out in the Main Test Bay of the Works, and it is of the greatest possible advantage to the Company and to its customers to be able, in this way, to make working tests on the complete equipment. Fig. 8 shows a portion of the Test Bay occupied by a complete automatic sub-station equipment, consisting of three 750 kW. rotary converters with their E.H.T. Switchgear and Transformers, and the automatic control and D.C. boards. The design, manufacture and testing of machines, transformers and control gear go hand in hand, with the result that any developments in one can be followed closely by suitable developments in the associated plant or apparatus.

On A.C. systems the operation of plant and control gear depends in a peculiar degree on auxiliary transformers of various types, and the importance of this apparatus is reflected in the separate article on page 22 of this issue, entitled "Instrument Transformers." The manufacture of the wide variety of types and sizes required is carried on in a special gallery in the Transformer Department of the Works, and the decision to manufacture this class of accessory apparatus has been wholly justified by the saving in time of delivery, the flexibility in design and the high standard of quality that have resulted.

The greater part of the switchgear produced at Stafford Works is for the control of alternating-current systems, and a complete range of the necessary apparatus can be supplied for working pressures up to 220,000 volts. For pressures of 44,000 volts and above, the apparatus is usually installed out of doors, and installations of this character are dealt with in a separate article on page 11. Of the very large number of installations supplied for operation at from 20,000 to 33,000 volts, a recent example is illustrated in Figs. 5 and 7, which show the bulk supply substation of the Ealing Corporation, probably the largest of its kind so far set to work in this country. Fig. 5 shows the 20,500-volt, 3-phase cellwork and Fig. 7 a number of 2,600-volt, 2-phase distribution cubicles, in which there are some 60 single-phase equipments in all.

FIG 8. COMPLETE AUTOMATIC SUBSTATION ON TEST.

FIG. 9. TRUCK-TYPE SWITCHBOARD WITH OIL BREAKERS OF LARGE RUPTURING CAPACITY.

D.C. boards have recently developed in the direction of high-voltage control for traction purposes and for radio transmission. Fig. 3 illustrates a typical switchboard for a 1,500-volt railway system, and Fig. 6 shows a board for 10,000-volt working in connection with wireless. In general, boards of this class are constructed on the "dead front" principle with the H.T. apparatus out of the operator's reach, and this principle has been extended in the board illustrated in Fig. 6 to the extent of mounting all the apparatus on porcelain insulators and placing the instruments behind glass panels.

Following the progressive policy of the Company, a large number of new designs have been brought out in the last few years, but space does not permit us to describe these at any length. Among the more important developments, there have been considerable additions to the lines of outdoor switchgear, automatic substations, high-speed circuit-breakers, oil-immersed switch fuses, flame-proof mining pillars, and an extension to the line of truck type switchgear. An example of the Company's large truck units is shown in Fig. 9.

Having shown quite briefly the facilities for the manufacture of switchgear at Stafford Works, it remains only to be stated that the Company's products cover every phase of the switchgear field, and are to be found in service in all parts of the world.

Outdoor Substations.

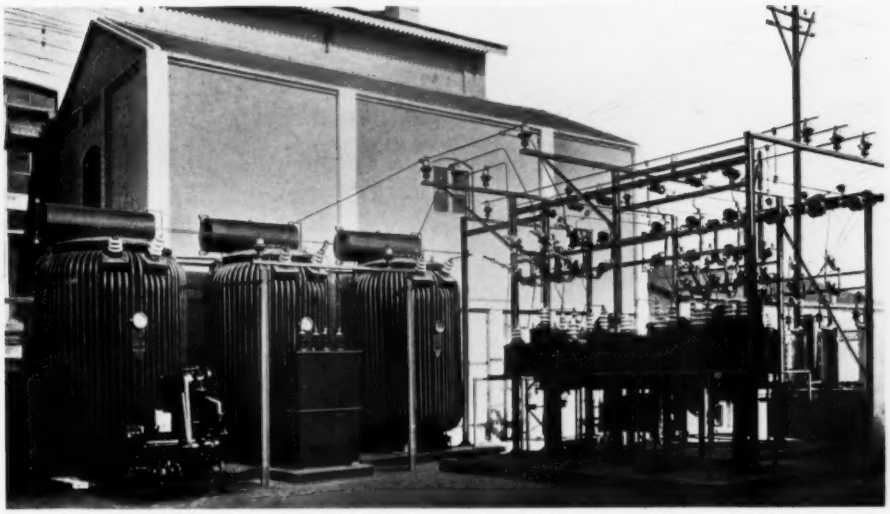


FIG. 1. 9,000-kVA, 22,000-VOLT OUTDOOR SUBSTATION UNDER CONSTRUCTION IN GREECE.

The employment of outdoor switchgear for large substations and switching centres is of comparatively recent growth—since, in fact, the commercial use of voltages of the order of 110 and 220 kV. At these voltages, the large clearances and headroom necessary make enclosing buildings unwieldy and expensive. For some time the use of outdoor substations was confined to overhead lines operating at very high pressures, and it was not considered worth while installing outdoor gear for pressures of 33,000 volts and under. Recently, however, the advantages of outdoor substations and the high price of building material and labour have led to the extension of outdoor installations down to quite low voltages. Fig. 1 shows a 22,000-volt substation with oil-break switchgear under construction in Greece; further examples are given later in the form of layout sketches.

For substations of small to medium size stepping down from say 6,000 or 11,000-volt mains, sheet steel transformer kiosks of the type illustrated in Fig. 4, page 13, have recently gained rapidly in favour. This type of substation is particularly useful at the present time in this country, when all districts are insisting not only upon a supply of electricity, but on the quick delivery of a cheap supply. In such cases it is an advantage to be able to run a ring main through several such districts and to take a number of complete factory built substation kiosks and instal them at suitable points on the ring. The special features of "English Electric" kiosk substations are described in the Company's publication 838.

Small pole-type substations consisting of a small power transformer connected to the line through an oil-immersed circuit-breaker, oil-immersed switch-fuse or simply through air-break switches and fuses, have come into use, solely on economic grounds, for individual supply along the run of a power transmission line. A typical instance is illustrated in Fig. 2. In such cases, the very cheapest form of substation must be provided, otherwise the cost of the necessary switchgear and transformer would prohibit a supply being given at all. Fig. 3 shows a semi-outdoor switching centre, comprising oil-immersed switch-fuses situated

at the foot of a transmission line pole.

The application of portable substations is rather special. For example, in brick fields and similar works covering a comparatively large area, it is an advantage to be able to follow up the work with the necessary machinery and step-down plant. The switchgear for this purpose may be either entirely of the outdoor type mounted on a framework on a truck, or it may be of the indoor type enclosed in a weatherproof kiosk, which, again, is mounted on wheels or a transportable platform. An example of the latter is shown in Fig. 5.

Another type of small substation employing the oil-immersed switch-fuse is shown in Fig. 6. This is practically a movable substation,

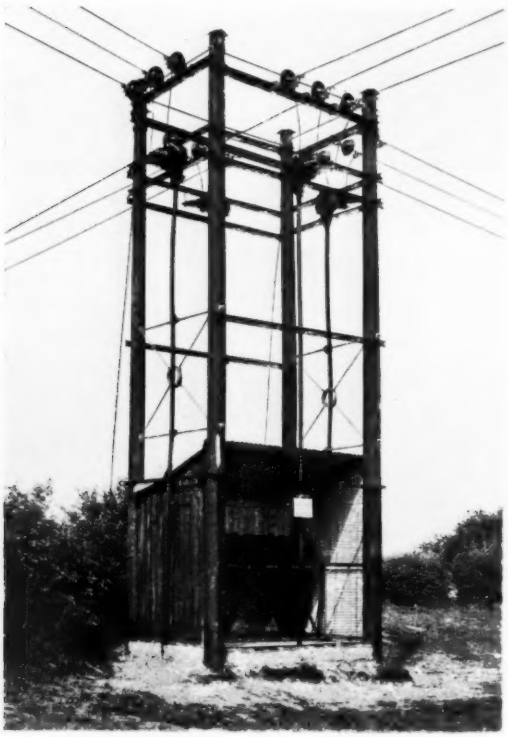


FIG. 3. PROTECTED OUTDOOR SWITCHING CENTRE EQUIPPED WITH OIL-IMMERSED SWITCH FUSES. (CHESTER).

FIG. 2. TYPICAL POLE-TYPE SUBSTATION. (WREXHAM).

as the sealing end attached to the transformer is of a special split type, having copper connecting links, which may be removed when the cable portion is unbolted. The oil switch-fuse and the transformer may then be moved separately to a fresh site, and the transformer sealing end reassembled without having disturbed any of the cable bonding.

OUTDOOR APPARATUS.

Fundamentally, there is very little difference between indoor and outdoor gear design except for the watershed insulators and general weatherproofing of joints. In practice, however, practically all switchgear for 66,000 volts and above is made in the outdoor pattern only.

A single-phase oil-immersed circuit breaker unit for 110 kV is shown in Fig. 7

FIG. 4. TYPICAL "ENGLISH ELECTRIC" KIOSK-TYPE TRANSFORMER SUBSTATION.

FIG. 5. L.T. SIDE OF A TRANSPORTABLE SUBSTATION.

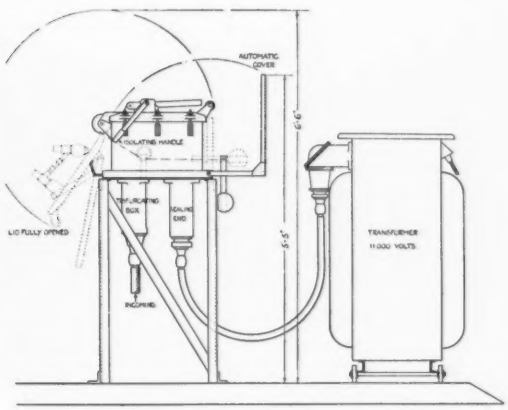


FIG. 6. SMALL SUBSTATION SUITABLE FOR TRANSFERRING FROM POINT TO POINT.

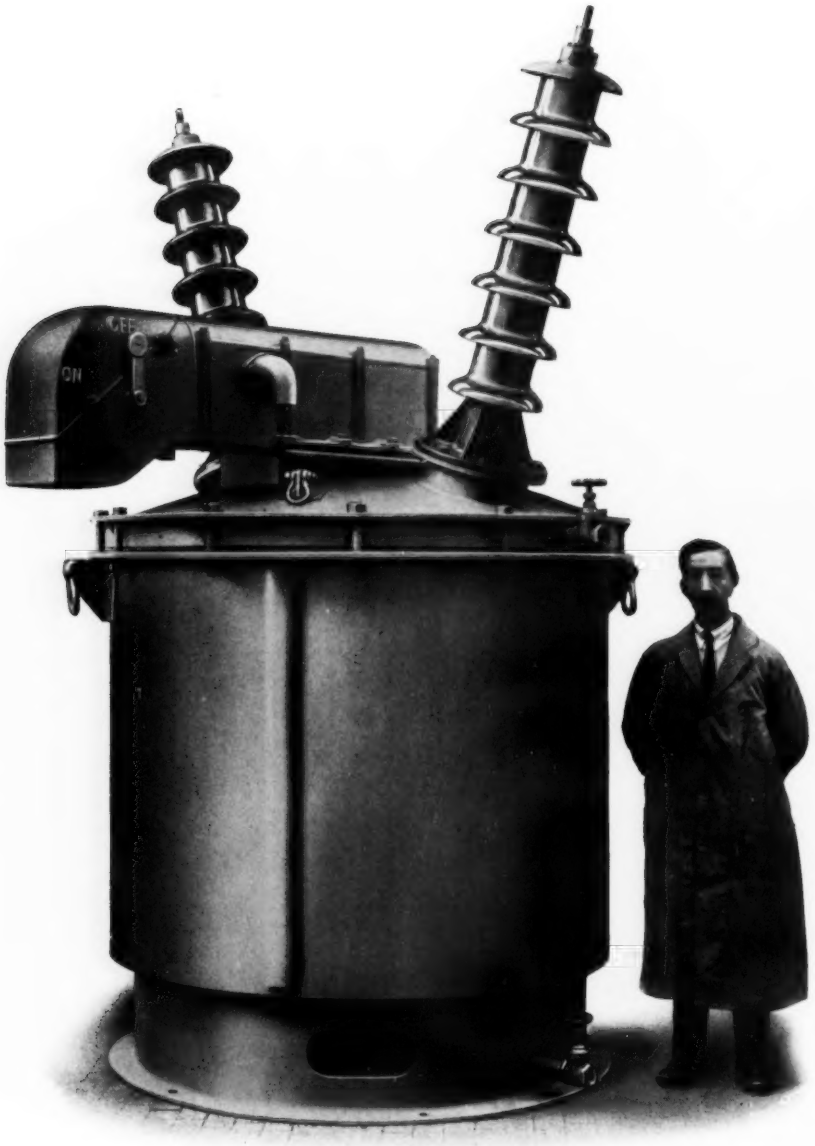


FIG. 7. 110,000-VOLT SINGLE PHASE OIL-IMMERSED CIRCUIT-BREAKER.

opposite. As will be seen, these breakers stand on the ground, and access is obtained to the interior through a manhole in the top plate. For lower voltages, the breakers are mounted on a framework, sufficiently high above the ground to enable the oil tanks to be lowered, tank-lowering mechanism being incorporated in the structure.

Two designs of " English Electric " oil circuit breakers for 50 to 132 kV are available, having different rupturing capacities. The design for the smaller rupturing capacity is a 2-break switch, having wedge contacts for both the main and sparking contacts. These are of the self-aligning spring finger type, of substantial design, arranged expressly to deal with heavy arcing without distortion. Both fixed and moving portions of the arcing contacts are readily replaceable, as will be seen from Fig. 8,

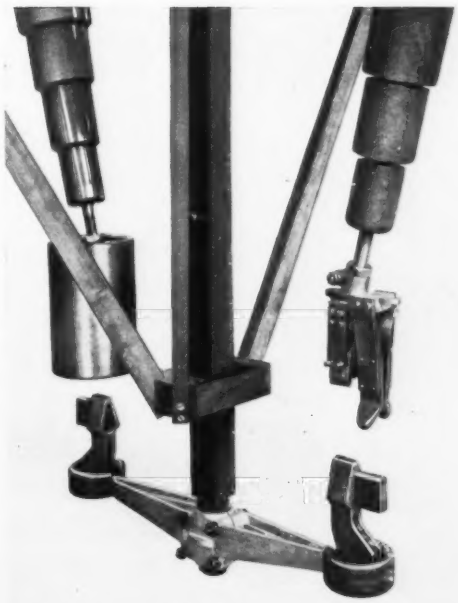


FIG. 8. 50 TO 132 kV OIL BREAKER. TWO-BREAK SWITCH.

which shows the contacts with one corona shield removed.

In the 4-break switch, the main contacts, of the laminated brush type, bridge directly between contacts fixed to the bottom of the insulator bushings. The break, however, takes place on an entirely different set of contacts of the finger type, four contacts in series per phase, whereby a very high speed of break is obtained without the attendant disadvantage of high plunger bar velocity. The contact system is illustrated in Fig. 9, which shows a view with two of the corona shields removed. The arcing contacts are arranged to break one after the other, the timing of the break being such that one of the four contacts will commence to open at the most favourable moment for rupturing the circuit, i.e., when the current is passing through its zero value.

Another important feature on these breakers is the incorporation of the " English Electric " patented combination of expansion chamber and baffle vents. A limited air

FIG. 9. 50 TO 132 kV OIL BREAKER. FOUR-BREAK SWITCH.

space immediately above the oil level acts as a cushion for the shock on opening circuit. This air space connects through perforated metal plates with an expansion chamber, which also accommodates the operating mechanism. The perforated metal plates tend to prevent oil throwing; at the same time, they allow the pressure in the main tank to be relieved and they also reduce the temperature and velocity of any oil and gas which is forced into the expansion chamber. From there, any oil thrown up drains back into the main tank, whilst the gas pressure is relieved by vent pipes leading from the expansion chamber and designed, of course, to prevent ingress of moisture.

The terminal bushings are of the condenser type, protected by porcelain rain shields on the outside. Two bushing type current transformers per phase can be accommodated, one on each of the terminal bushings. The dome-shaped top plate is of cast steel and supports the whole of the terminal bushings, contacts and operating mechanism, and the oil tank. The tanks are circular and are constructed of heavy boiler plate; they are provided with insulated linings spaced apart from the tank to ensure a layer of quiescent oil around the tank walls under all conditions. The operating mechanism is contained in the enclosure which forms part of the expansion chamber casting, and removable covers give access for inspection or adjustment. Operation is by solenoid or motor, the latter being run from either an A.C. or a D.C. supply. If no auxiliary supply is available, the motor operating gear can be worked from a 12-volt portable battery, which can be removed periodically for charging. It is possible even

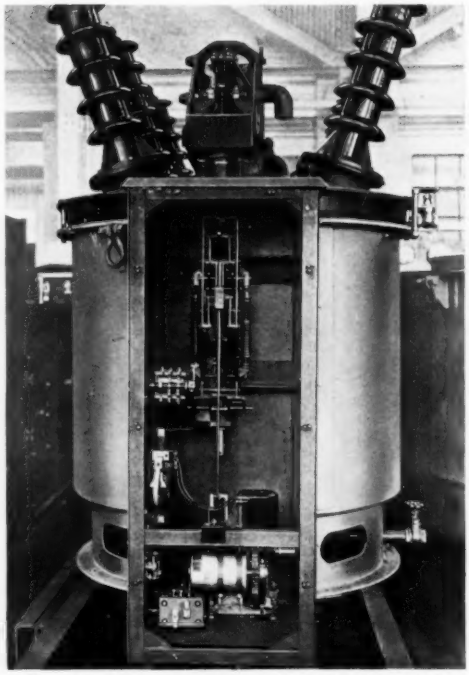


FIG. 10. MOTOR-DRIVEN OPERATING MECHANISM FOR 110,000-VOLT BREAKER.

FIG. 11. OUTDOOR OIL CIRCUIT BREAKER FOR 66,000 VOLTS.

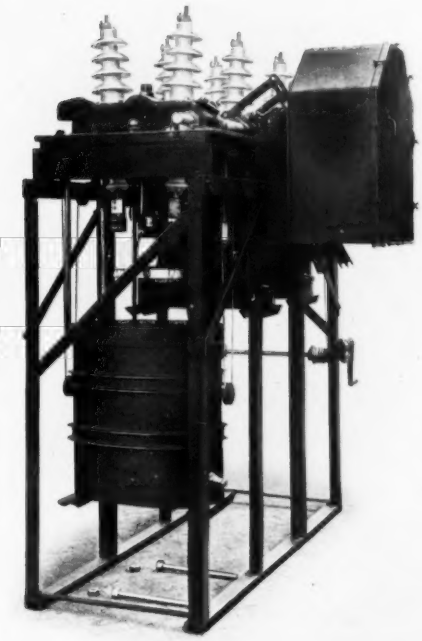


FIG. 12. OUTDOOR OIL CIRCUIT-BREAKER FOR 22,000 VOLTS.

to dispense with this battery for unattended substations where the operator is provided with a car, arrangements being made to plug in the car battery for closing the switches. A D.C. motor operating pedestal can be seen in Fig. 10.

Up to and including the 66,000-volt size, oil breakers are mounted on substantial framework, with self-contained tank lowering mechanism, as illustrated in Fig. 11, which shows a triple-pole breaker of the 4-break type under construction. Fig. 12 shows a typical 3-phase breaker for 22 kV. with the solenoid operating mechanism in a self-contained weatherproof enclosure fixed to the structure.

Air-break switches of the horn-break type are sometimes used in place of oil circuit-breakers, and occasionally are used to bridge the breakers so that the latter can be isolated and inspected without interrupting the supply. Descriptions of these switches up to 220 kV., and also of the isolating switches, are given in the Company's publications 807 and 833. For the higher voltages, the problem is mainly one of additional insulation.

Current and potential transformers are dealt with in a separate article in this issue. For 44 kV. and over, bushing type current transformers are generally used. Present day practice at these pressures tends towards the elimination of expensive potential transformers by metering entirely on the L.T. system.

Oil-immersed switch-fuses are frequently used in place of oil circuit-breakers in connection with kiosks and small outdoor substations. The popularity of this class of apparatus is steadily increasing, especially since the production of The English Electric Company's design complying with the Home

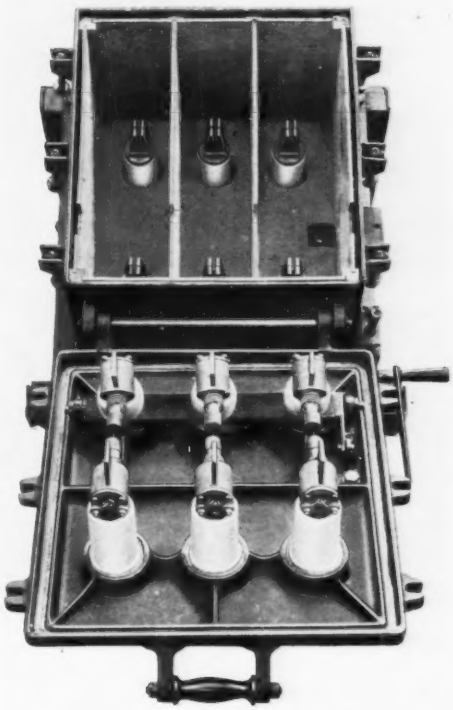


FIG. 13. "ENGLISH ELECTRIC" OIL-IMMERSED SWITCH FUSE.

Office regulations and having a definite rupturing capacity of 50,000 kVA. For this apparatus the fuses are held between spring-loaded plungers attached to contacts mounted on insulators supported by the hinged lid, as shown in Fig. 13. When the lid is closed, the contacts engage with fixed contacts in the bottom of the tank. The whole is immersed in oil contained in a substantial cast steel tank. An interlocked isolating device, the handle of which is shown in Fig. 14, ensures that the circuit must be opened before the lid is opened, and that the lid must be closed before the switch is closed. A further attachment, especially suitable for outdoor use, is an automatic protection cover, which, when the lid of the switch is opened, automatically covers the oil tank containing the fixed contacts. An illustration of the

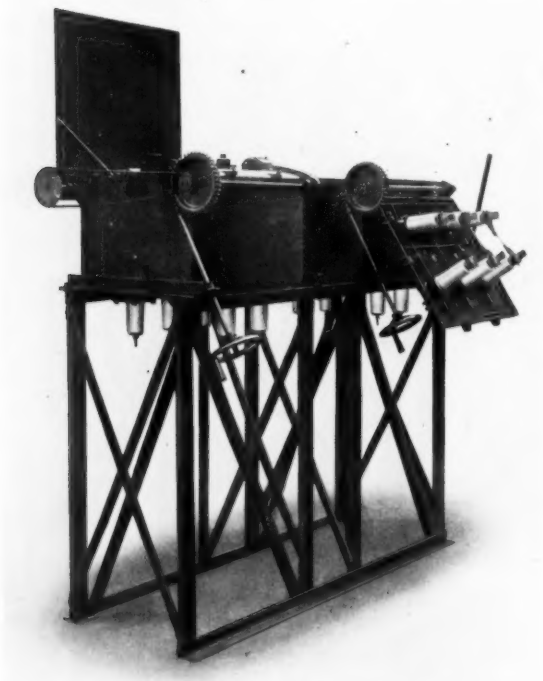


FIG. 15. OUTDOOR 33,000-VOLT OIL SWITCH FUSES SHOWING AUTOMATIC PROTECTION COVERS.

FIG. 14. OIL SWITCH FUSE SHOWING INTERLOCKED ISOLATING HANDLE.

33,000-volt oil-immersed switch fuse for outdoor working is given in Fig. 15. Special arrangements are made in this case to enable the contacts on either side of the switch fuse to be brought out to connections through the lid when the fuse portions are removed. This provides ready access to the cable or transmission line for testing or earthing purposes.

OUTDOOR SUBSTATION LAYOUTS.

Fig. 16 shows a 110 kV. station with duplicate busbars. This controls four step-up transformer banks, each bank directly coupled to a 10,000 kW. alternator, and also four feeders, each with lightning arrester gear. The oil circuit-breakers used are as illustrated in Fig. 7. The duplicate busbars have an oil circuit-breaker busbar coupling

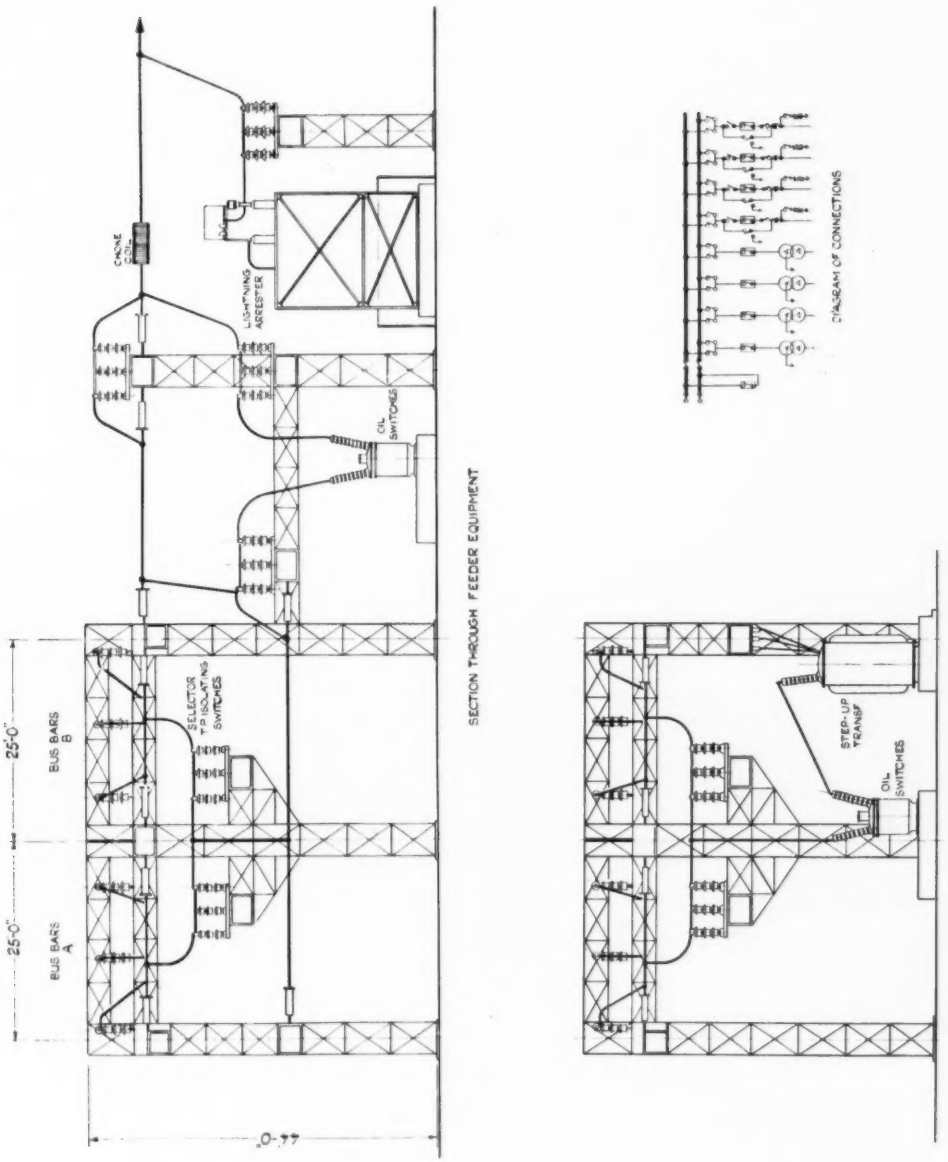


FIG. 16. LAY-OUT OF 110 kV. SUBSTATION FOR CONTROLLING 40,000 kW OF PLANT.

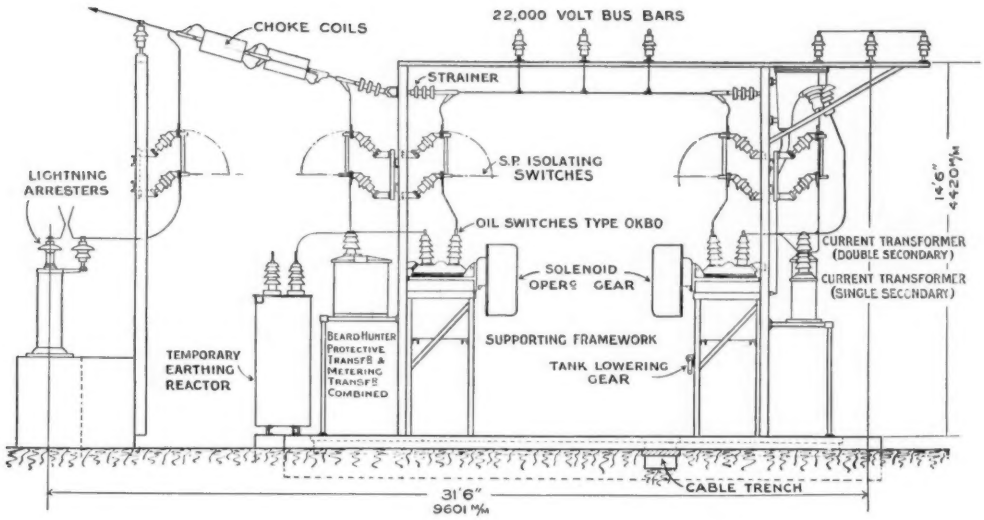


FIG. 17. LAY-OUT OF 22,000-VOLT SUBSTATION IN GREECE.

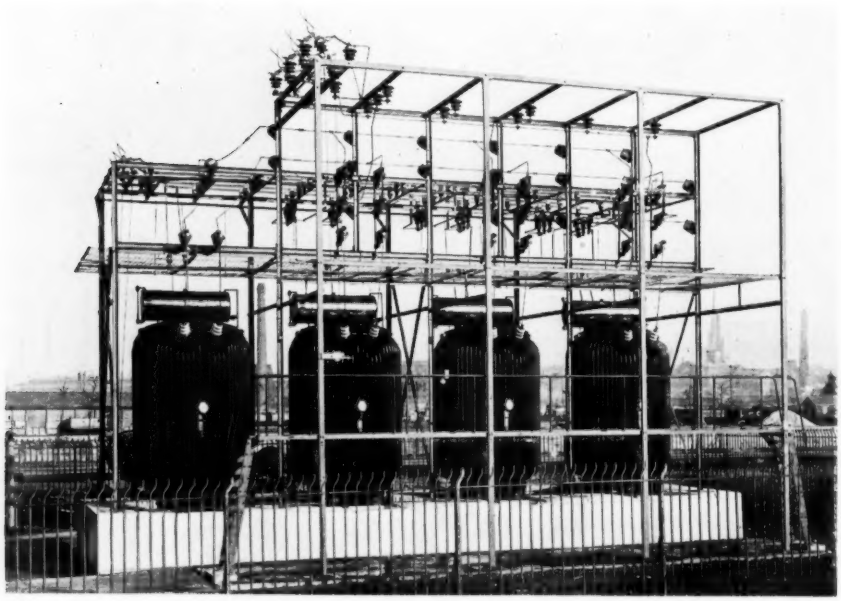


FIG. 18. 6,600/33,000-VOLT, 8,700-kW SUBSTATION AT PRESTON.

equipment and the whole station is arranged to facilitate extensions. It will be observed that the feeder oil circuit-breakers are bridged by isolating switches, so that the breakers themselves can be isolated for inspection without interrupting the supply. The isolating switches used are of the 3-phase rotating centre-pillar type, mechanically operated from handles fixed on the upright supports.

A simpler form of substation is shown in Fig. 19, which illustrates the layout of one of several substations for both 50 and 110 kV. on a large hydro-electric scheme in New Zealand. Here again, the oil circuit-breakers are bridged by air-break switches in a similar manner to that shown in Fig. 16, but in this case the switches are of the horn-break type, mechanically operated from below. The step-down transformers are connected in delta on the high-tension side, which necessitated a cantilever projection, as shown, to support the connections which could not run direct. The scheme of connections at this point is shown in the smaller sketch.

A substation layout for 22,000 volts is shown in Fig. 17. In this example, the incoming feeder is protected by Beard-Hunter gear, and the protective current transformer and metering current transformer for each phase are contained in one case. From the busbars, two feeders lead away through oil circuit-breaker equipments. One feeds a step-down transformer for local power supply, the connections to this transformer being guided by the supporting insulators on the extreme right; the other feeds a rotary converter for traction supply, and the connections for this pass up to the inverted cable box shown above the current transformers on the right, the cable passing thence to an adjacent building. The oil circuit-breakers used in this substation are illustrated in Fig. 12.

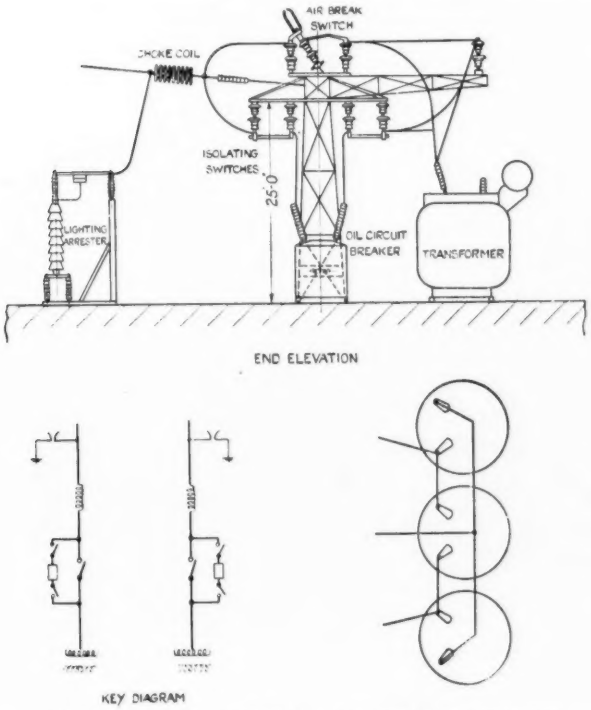


FIG. 19. LAY-OUT OF 50 kV. AND 110 kV. SUBSTATIONS. (NEW ZEALAND).

As an example of outdoor substations provided with air-break switches, reference may be made to Fig. 18 which shows one of the 6,600/33,000-volt installations provided at each end of the interconnecting lines between the Ribble power-station at Preston and those at Blackburn and Blackpool.

It will be seen that there are many types of outdoor substation, of which only typical examples are given above. The field for this class of apparatus is practically unlimited, and the increasing use of outdoor switching, even down to comparatively low pressures, shows that the possibilities of this gear and the saving effected in buildings are being realised and exploited to an increasing extent.

Instrument Transformers.

The purpose of this article is to outline the theory of Instrument Transformers, and to describe some of the types made by The English Electric Company Limited, at Stafford Works.

Instrument Transformers are essential for the measurement and control of alternating current above about 550 volts or about 200 amperes. They render it possible to use standard meters and relays for any voltage or current. The requirements to be fulfilled, arranged in order of importance, are as follows:

(1) High Breakdown Value.
(2) Accuracy.
(3) Economy of space and material.

The insulation between the high-tension and low-tension windings of these transformers is submitted to very severe pressure tests. Having withstood these tests, the transformer insulation can be relied on as a barrier protecting the control gear or instruments from line pressure.

It is important to realise that the rating of an instrument transformer is not a thermal rating, but an accuracy rating. A 15 V.A. Current Transformer is one which gives its specified accuracy when the secondary is closed through an impedance of not more than ·6 ohm. For full load at 15 V.A. the secondary pressure is 3 volts at 5 amps. A 50 V.A. Potential Transformer is one which gives its specified accuracy when the secondary is closed through an impedance of not less than 242 ohms. The secondary current at 50 V.A. loading is ·455 amp. at 110 volts.

Current Transformers.

Fig. 1 is a vector diagram of a current transformer of 1/1 ratio at 5 amps. secondary current and 15 V.A. load for two cases. In case I the secondary load impedance is equal to ·6 ohm non-inductive. The secondary current I_2 = OA is taken as the vector of reference. OB is the secondary induced voltage and is the vector sum of the external voltage I_2R and the resistance and reactive drops in the secondary winding. OC is the exciting current, the components of which are the magnetising current and the iron loss current. In Fig. 1, OC is drawn 15 to 30 times larger than it would be for an actual transformer. Its magnetising current component is at right angles to OB. The primary current I_1 is now equal to AC; i.e., to the vector sum of the reversed secondary current AO and the exciting current OC. The angle OAC is the phase error of the transformer, and the ratio error is $\frac{I_1 - I_2}{I_1} \times 100$.

In case II (shown chain dotted) the

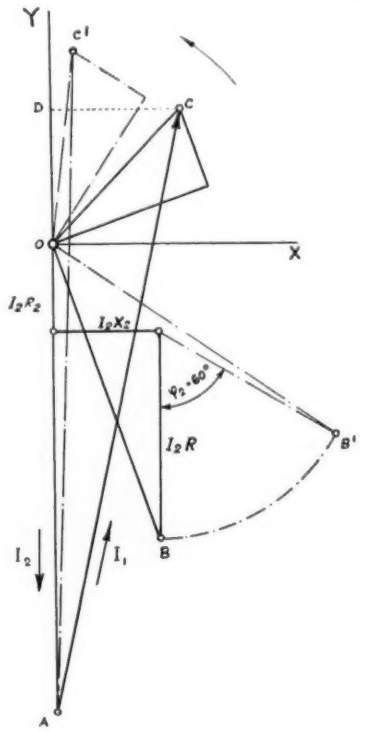


Fig. 1. Vector Diagram for Current Transformer.

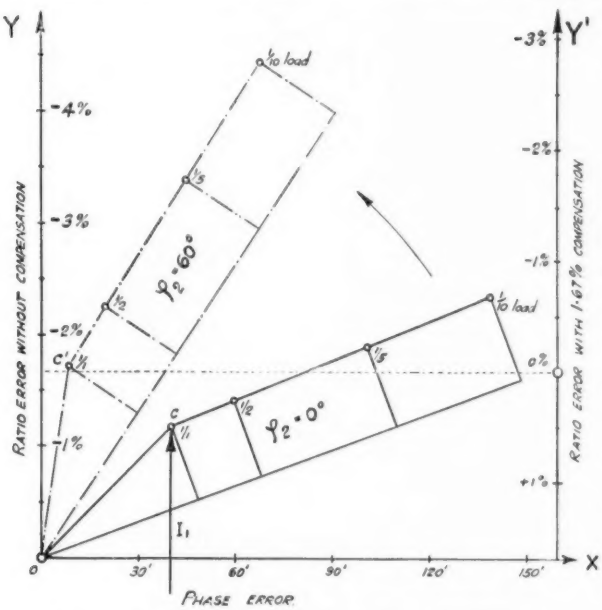


FIG. 2. ERROR DIAGRAM FOR CURRENT TRANSFORMER.

secondary load impedance is again ·6 ohm, but the phase angle of the secondary load $\phi_2 = 60°$. The primary current is now OC¹ and it is seen that for inductive secondary loads the phase error is smaller, but the ratio error greater than for non-inductive loads.

As the actual magnitude of OD and DC is very small compared to OA, approximate values of the ratio and phase errors can easily be shown on the diagram as follows:—

(1) Ratio error $\frac{I_1 - I_2}{I_1} \times 100 =$ approximately $\frac{O\ D}{OA \times \cdot 01}$; *i.e.*, if OY is divided into units, each of which is equal to OA × ·01, it is then a scale from which the percentage error can be read off directly.

(2) Similarly, as the phase error is approximately equal to $\frac{DC}{OA} \times \frac{360°}{2\pi} = \frac{DC}{OA \times \cdot 0175}$ degrees, OX can be divided into units equal to OA × ·0175, and is then a scale from which the phase error in degrees can be read off directly.

Fig. 2 gives the upper part only of a diagram of this kind for $\phi_2 = 0°$ and 60° respectively, at 1/1, 1/2, 1/5 and 1/10 loads, i.e., for secondary currents of 5, 2½, 1 and ·5 amps. The points C and C¹ for 1/1 load (5 amps.) are as in Fig. 1. To enable the use of the same error scales at all loads, OA is taken to represent the secondary current in each case; i.e., the ampere scale is altered in inverse proportion to the load. If the exciting current were proportional to the load, then obviously

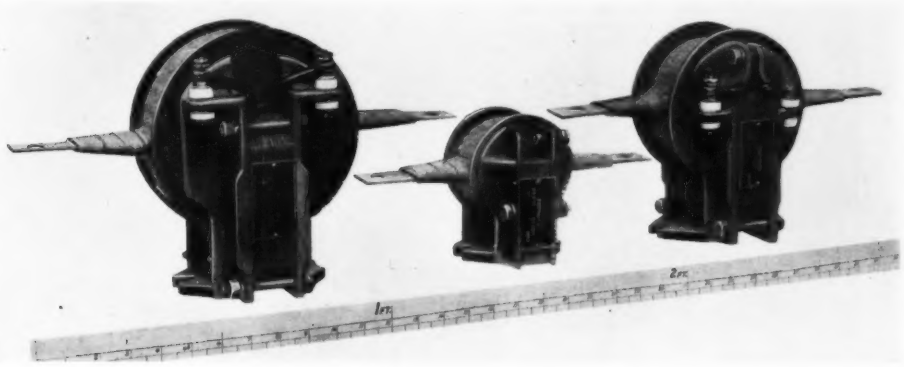
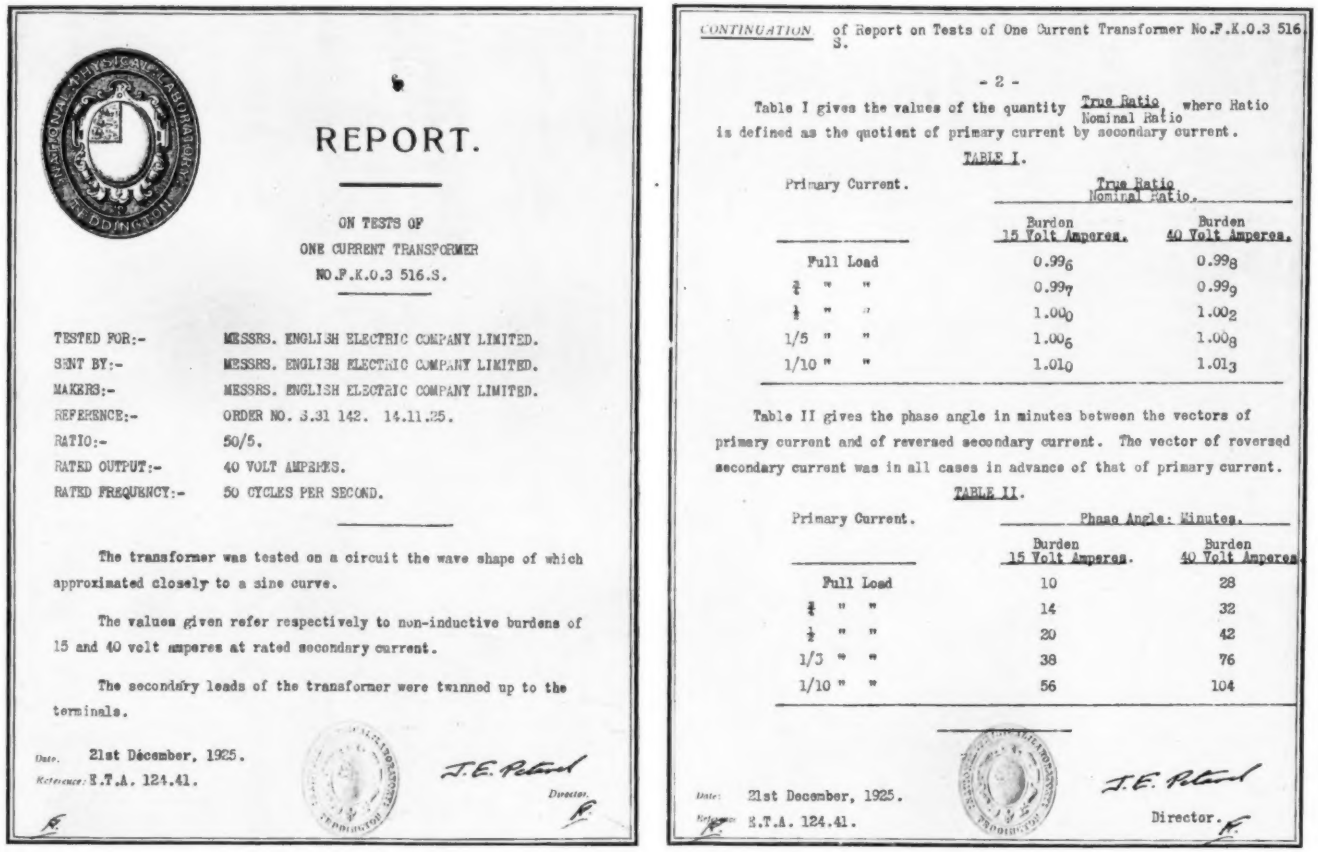


FIG. 3. OPEN-TYPE CURRENT TRANSFORMERS FOR 40, 5 & 15 V.A.



REPORT.

ON TESTS OF
ONE CURRENT TRANSFORMER
NO.F.K.0.3 516.S.

TESTED FOR:-	MESSRS. ENGLISH ELECTRIC COMPANY LIMITED.
SENT BY:-	MESSRS. ENGLISH ELECTRIC COMPANY LIMITED.
MAKERS:-	MESSRS. ENGLISH ELECTRIC COMPANY LIMITED.
REFERENCE:-	ORDER NO. 3.31 142. 14.11.25.
RATIO:-	50/5.
RATED OUTPUT:-	40 VOLT AMPERES.
RATED FREQUENCY:-	50 CYCLES PER SECOND.

The transformer was tested on a circuit the wave shape of which approximated closely to a sine curve.

The values given refer respectively to non-inductive burdens of 15 and 40 volt amperes at rated secondary current.

The secondary leads of the transformer were twinned up to the terminals.

Date. 21st December, 1925.
Reference: E.T.A. 124.41.

J.E. Petavel
Director.

CONTINUATION of Report on Tests of One Current Transformer No.F.K.0.3 516 S.

- 2 -

Table I gives the values of the quantity $\frac{\text{True Ratio}}{\text{Nominal Ratio}}$ where Ratio is defined as the quotient of primary current by secondary current.

TABLE I.

Primary Current.	True Ratio / Nominal Ratio.	
	Burden 15 Volt Amperes.	Burden 40 Volt Amperes.
Full Load	0.99_6	0.99_8
¾ " "	0.99_7	0.99_9
½ " "	1.00_0	1.00_2
1/5 " "	1.00_6	1.00_8
1/10 " "	1.01_0	1.01_3

Table II gives the phase angle in minutes between the vectors of primary current and of reversed secondary current. The vector of reversed secondary current was in all cases in advance of that of primary current.

TABLE II.

Primary Current.	Phase Angle: Minutes.	
	Burden 15 Volt Amperes.	Burden 40 Volt Amperes.
Full Load	10	28
¾ " "	14	32
½ " "	20	42
1/5 " "	38	76
1/10 " "	56	104

Date: 21st December, 1925.
Reference: E.T.A. 124.41.

J.E. Petavel
Director.

FIG. 4. REPRODUCTION OF N.P.L. REPORT ON A STANDARD 40 V.A. CURRENT TRANSFORMER.

its vector would always coincide with OC (or OC^1) and the errors would not vary with the secondary current. As, however, the permeability of the core decreases at low loads, the errors increase. Scale Y shows the ratio errors on an uncompensated transformer. Scale Y^1 shows them on a transformer on which the ratio is adjusted by turn compensation. The diagram shows clearly the relationship between load, exciting current, load power factor and accuracy.

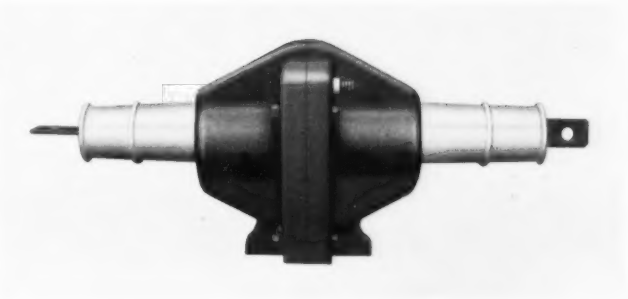


FIG. 5. 11,000 VOLT COMPOUND-FILLED CURRENT TRANSFORMER.

The different classes of insulation used in " English Electric " designs are shown in the following table:—

Insulation.	Type of Current Transformer.	Line Voltage up to
Press-board	Air-Cooled	660
Taped Varnished Cloth, reinforced by leatheroid tubes	Air-Cooled	6,600
Porcelain	Air-Cooled	11,000
	Compound-Filled	38,000
	Oil-Immersed	38,000
Bakelised Paper	Air-Cooled	11,000
	Compound-Filled	33,000
	Oil-Immersed	66,000
Air	Air-Insulated Outdoor type	Any Voltage

Both " Shell " and " Core " types of transformer are made. The laminations are punched from sheets of high-grade silicon steel. To obtain the degree of accuracy required, the working flux densities are less than one-tenth of those used on power transformers.

About 75 per cent. of the current transformers made are of the open or air-cooled type. The insulation is protected from absorption of moisture by thorough drying in vacuum, followed by impregnation and baking. The compactness of the transformers of this class renders them specially suitable for truck-type switchgear.

Fig. 3 shows a group of open-type transformers for 40 V.A., 5 V.A. and 15 V.A. respectively. The 40 V.A. and 15 V.A. types are used up to 6,600 volts; their performance is in accordance with the British Standard Specification No. 81-1919. Fig. 4 opposite is a reproduction of an N.P.L. Report on a duplicate of the 40 V.A. transformer illustrated. Transformers of this rating are usually put in where special accuracy of watt-hour meters at low loads is required. The 5 V.A. type is for use up to 3,300 volts on circuits in which phase error is unimportant.

Standard 15 V.A. and 40 V.A. compound-filled current transformers are duplicates of the open types as regards electrical design and performance. They are metal clad, provided with porcelain insulators, and are built for 6,600 and 11,000 volts. They are specially suitable for tropical climates, or for situations where the transformer is exposed to condensation or to accumulation of dust. Fig. 5 shows

a 40 V.A. transformer of this class for 11,000 volts.

Figure 6 shows a current transformer without primary for 3,000/5 amps. The punchings forming the magnetic circuit are jointless.

The effect of open-circuiting a standard current transformer of this ratio is worth noting. The full primary ampere-turns now act as a magnetomotive force on the iron circuit, so that the core is saturated. The secondary voltage rises to about 180 volts at 50 cycles. If the transformer ratio were 3,000/2·5 amps., then the open-circuit secondary voltage would be 360 volts. The temperature rise due to the iron loss at saturation is not sufficient to damage the transformer. The accuracy of the transformer is hardly affected.

Figs. 7 and 8 show indoor-type current transformers for 38,000 and 35,000 volts respectively. Both are compound-filled, porcelain-insulated, wound types. Over 140 of the former type were supplied recently on a large overseas contract. The 35,000-volt type is for " through wall " mounting. It has one primary winding only but two separate magnetic circuits, each of which has a secondary winding. One of these is used for metering only, and the other for protective relays.

In Figure 10 a 22,000-volt, weatherproof unit consisting of one metering and one protective transformer is shown withdrawn from its case. The Metering Transformer is mounted nearer the cover and is a standard type. Its performance is shown on the N.P.L. report reproduced in the Company's Publication No. 580. The primary coil is insulated by porcelain bobbins and pressboard barriers. The protective transformer is described on page 28. All the L.T. leads are taken to a terminal box with sliding cover. The top of the H.T. Bushing is sealed by a porcelain cap, not shown in the illustration.

Fig. 11 is a weatherproof high-voltage current transformer on which air is the insulating medium. Though of comparatively large size, this type is cheaper than the oil-immersed type for voltages over 40,000. It can be built for any voltage.

FIG. 6. 3000/5 AMPERE CURRENT TRANSFORMER.

FIG. 7. 38,000-VOLT COMPOUND-FILLED TRANSFORMER.

PROTECTIVE TRANSFORMERS. A considerable number of special current transformers have been built for differential feeder protective systems of both the split conductor and the balanced voltage types. Fig. 9 shows a single-turn split-conductor protective transformer for 200 amperes per half-conductor and 11,000 volts, in an aluminium alloy case for "through wall" mounting. A

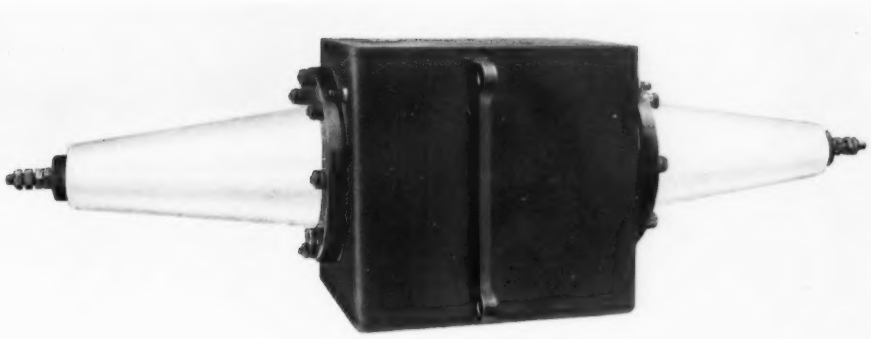


FIG. 8. 35,000-VOLT COMPOUND-FILLED "THROUGH-WALL" CURRENT TRANSFORMER.

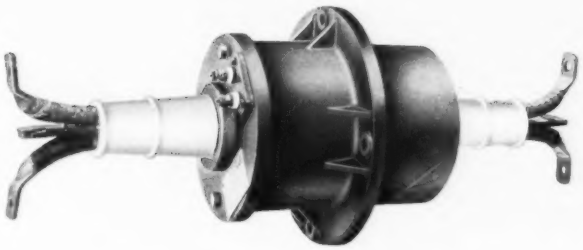


FIG. 9. SINGLE-TURN SPLIT-CONDUCTOR PROTECTIVE TRANSFORMER, "THROUGH-WALL" TYPE.

FIG. 10. 22,000-VOLT WEATHERPROOF METERING AND PROTECTIVE TRANSFORMER (OUT OF CASE).

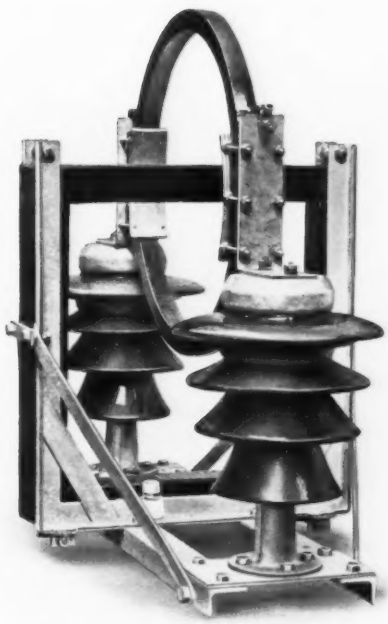


FIG. 11. OUTDOOR CURRENT TRANSFORMER FOR THE HIGHEST VOLTAGES.

smaller type for 6,600 volts and 100 amperes per half-conductor is made in the standard 40 V.A. cast iron case shown in Fig. 5. Occasionally the multiple turn high reactance type is supplied for existing feeders not fitted with split switches. Sensitive relays taking ·5 V.A. on minimum setting are used for split-conductor protection, and the minimum fault current necessary to trip is about 25 amperes.

The lower of the two transformers shown in Fig. 10 is a balanced-voltage transformer of the type used for the Beard-Hunter sheathed pilot system of feeder protection. The magnetic circuit is formed of ring punchings with an air-gap. The transformer has a straight line characteristic up to very high overloads. Very sensitive relays operating at about ·02 V.A. are used, and the standard minimum fault setting is 70 amperes. The standard 11,000-volt transformer of this type is supplied in a case which is identical with that shown on Fig. 9.

Merz-Price balanced-voltage protective transformers with drooping characteristic are similar in general construction and outward appearance to the above, but have a much smaller air-gap. They are used with unscreened pilot wires, and are only supplied where the feeder is not exposed to high overloads caused by external faults, and where a fairly high fault setting is permissible.

Any of the standard types of "English Electric" current transformer can be used for Merz-Price circulating-current protection.

Potential Transformers.

Fig. 12 shows the upper part of a vector diagram for a potential transformer of 1/1 ratio, constructed on similar lines to the current transformer diagrams given above. The vector of reference OA (not shown) is in the same position as in Fig. 1. It now represents the secondary induced voltage V_2. OH is the voltage drop at no load (i.e., transformer on open circuit). It is equal to the vector sum of OF and FH, where OF = exciting current x primary resistance, and FH = exciting current x primary reactance.

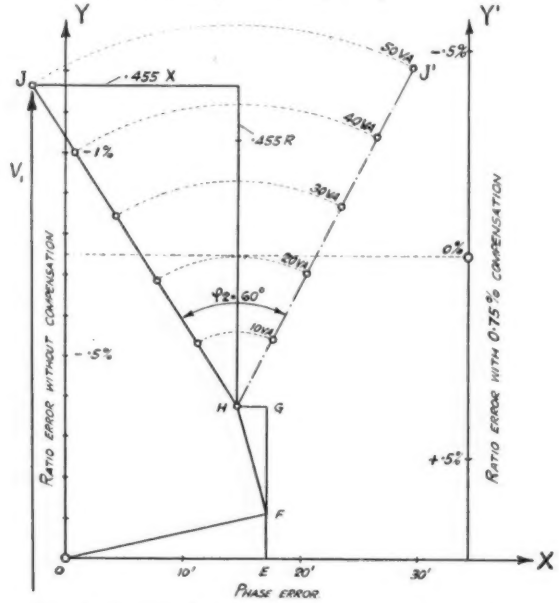


FIG. 12. VECTOR DIAGRAM FOR POTENTIAL TRANSFORMER.

When the secondary circuit of the transformer is closed, the transformer is on load and an additional voltage drop—the load drop—takes place. At 50 V.A. non-inductive load, this drop is H J = $\cdot 455 \times \sqrt{R^2+X^2}$ (where R and X are the total effective resistance and reactance respectively of the transformer). AJ is now the primary voltage and is equal to the vector sum of the reversed secondary voltage AO, the no-load drop OH and the load drop HJ.

The diagram also gives the primary voltage OJ^1 for 50 V.A. inductive load and $\phi_2 = 60°$. H J and H J^1 are subdivided to show the primary voltages at 10, 20, 30 and 40 V.A.

OY and OX are now calibrated as before by division into units equal to OA x ·01 and OA x ·0175 to give the ratio error and phase error respectively of an uncompensated transformer ·by

direct reading. Similarly the scale Y^1 shows the ratio error on a transformer with turn compensation.

The following results are taken from a special test on a three-phase 6,600-volt potential transformer recently supplied:—

Terminals.	Burden Zero.		Non-inductive Burden of 50 V.A. per phase.	
	Ratio Error. %	Phase Error. Minutes.	Ratio Error. %	Phase Error. Minutes.
A B	+ ·5	+ 16	— ·2	0
B C	+ ·5	+ 18	— ·2	— 2
C A	+ ·3	+ 16	— ·4	— 2

NOTE.—The phase error is given as positive when the vector of reversed secondary voltage is in advance of the vector of primary voltage. Thus the phase errors in Fig. 12 at zero burden, 59 V.A. non-inductive burden, and 40 V.A. inductive burden are + 14, — 3 and +27 minutes respectively.

The number of types of potential transformer is much smaller than that of current transformers. The Company have adopted the "core" type throughout, for both single and three-phase potential transformers. The cores are built of high-grade silicon steel laminations, and all joints are interleaved. The working flux densities are kept low enough to enable the transformers to be used on voltages which are 10 per cent. higher than the rated voltage, without any considerable loss of accuracy. The windings are circular and concentric, and are insulated from each other by bakelised paper tubes.

For pressures above 12,000 volts the L.T. windings are mounted next to the core and the H.T. windings are assembled outside. On all types up to 12,000 volts inclusive, however, this arrangement is reversed. The primary resistance is thereby reduced, so that the vector OE in Fig. 12 becomes smaller, and the phase angle is improved. Up to 3,300 volts, both air-cooled and oil-immersed potential transformers are made; above this voltage, all standard types are oil-immersed.

The high-tension coils are wound with edge strips, and are of a special patented type. In ordinary edge strip windings, one strip is inserted at each end of each layer of the coil, and its thickness is equal to the diameter of the conductor. In the construction covered by Patent No. 230964, the number of edge strips used is halved, and the thickness of each strip doubled. Each strip now extends across and supports two layers of the coil, and is kept rigidly in position by being inserted in the fold of the insulation between layers. In 3½ years over 2,000 potential transformers with this type of coil have been put into commission

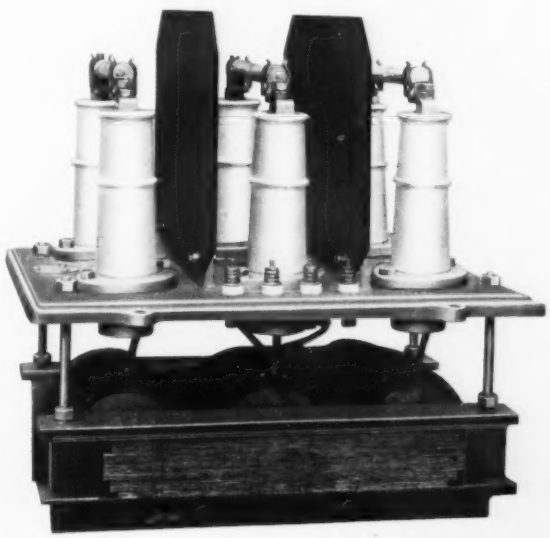


FIG. 13. 11,000-VOLT OIL-IMMERSED POTENTIAL TRANSFORMER WITHDRAWN FROM ITS TANK.

FIG. 14. 22,000-VOLT POTENTIAL TRANSFORMER.

and no case of faulty windings has been reported. The high insulation values obtained are shown by the following typical test. A standard coil of 3,400 turns in 57 layers was submitted to over-potential tests in hot oil. An induced pressure of 27,000 volts at 125 cycles was applied across the coil for five minutes, without breakdown, the pressure between adjacent layers being 950 volts. When the test pressure was raised to 30,000 volts, flash-over took place in a radial direction across the face of the coil. The radial depth of this coil was 1·12 in. and the total axial length only 1·55 in.

The insulation on the end turns of potential transformers for voltages over 1,100 is reinforced by increasing the size of the conductor and the thickness of the insulating covering and by winding spacers between adjacent turns. On 22,000-volt transformers, for example, three coils adjacent to each terminal are very heavily reinforced, and the line coils are of the disc type, consisting of five turns only.

On single-phase types over 22,000 volts, and on three-phase types over 20,000 volts, however, the windings are protected by choke coils mounted under oil on the bushings and connected in series between the H.T. terminals and the transformer winding. These choke coils have no iron core, so that their reactance at normal frequency is negligible. They present, however, a high reactance to high-frequency transients caused by switching-in effects or line disturbances, and thus flatten out any steep wave front before it reaches the transformer. The end-turn reinforcement can, therefore, with safety be reduced.

Fig. 13 shows a standard 11,000-volt, three-phase, oil-immersed potential transformer withdrawn from its tank. The H.T. coils are next to the core and the L.T. coils are outside, wound on insulating tubes. H.T. fuses and bakelite phase barriers are mounted on the cover. On transformers for use in truck gear the insulators are mounted on the side of the tank, so that the overall height is considerably reduced.

Fig. 14 shows a three-phase, 22,000-volt potential transformer withdrawn from its case. On conventional high-voltage designs, comparatively long cores are used, and mounted vertically in the case. By using the patented type of edge strip coils and choke coil protection, this transformer has been designed with a very short core, so that it can be suspended horizontally from the cover. The overall size, including terminals, of a three-phase 33,000-volt potential transformer of this type is only 33 in. x 25¾ in. x 38 in. high.

The "English Electric" Magnetic High-Speed Circuit-Breaker.

The development of electric traction has led to the concentration of great plant capacity in supply stations and substations; this, in turn, has directed attention to the necessity of protecting rotary converters and other plant from the effects of the frequent heavy short-circuits to which traction systems are liable. The English Electric Company has followed every phase of these developments with close attention and has taken a prominent part both in the improvement of Rotary Converter design in order to render these machines inherently suitable for the severest heavy traction condition, and also in the production of devices capable of giving adequate protection on H.T. direct-current systems.

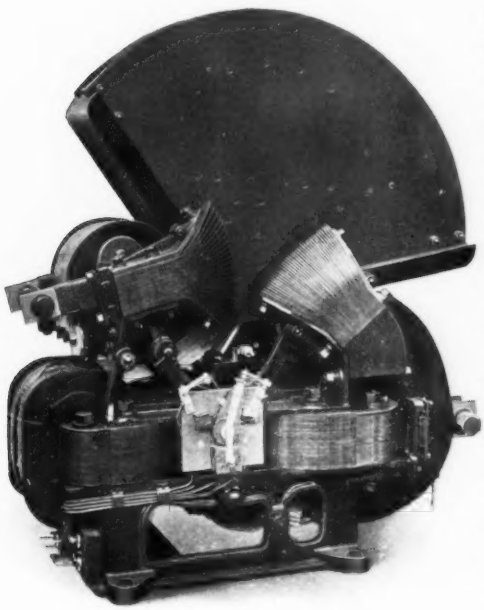


Fig. 1. "English Electric" High-Speed Circuit-Breaker.

Experience has shown that the most practical way of limiting the disturbing effects of a short-circuit on such systems is to instal apparatus which will automatically interrupt the D.C. supply with extreme rapidity.

The design of the "English Electric" Patented high-speed breaker has been worked out with great care and considerable experimental work, often carried out under the severe conditions which are met with in modern traction substations. Fig. 1 is a general view of a typical breaker ready for service, while Fig. 2 shows the main constructional features.

To obtain in the highest degree the essential properties of extremely rapid opening and shortest possible duration of arcing, certain novel features have been introduced with most successful results. The chief advantages claimed are as follows:—

(1) It is closed and held in by magnetic force only, the magnitude of which is small since there is no pull-off spring to be overcome.

(2) It is opened by magnetic forces only.

(3) Great rapidity of opening obtained by the elimination of springs, catches, etc.

(4) Speed of opening increases with the severity of the short circuit.

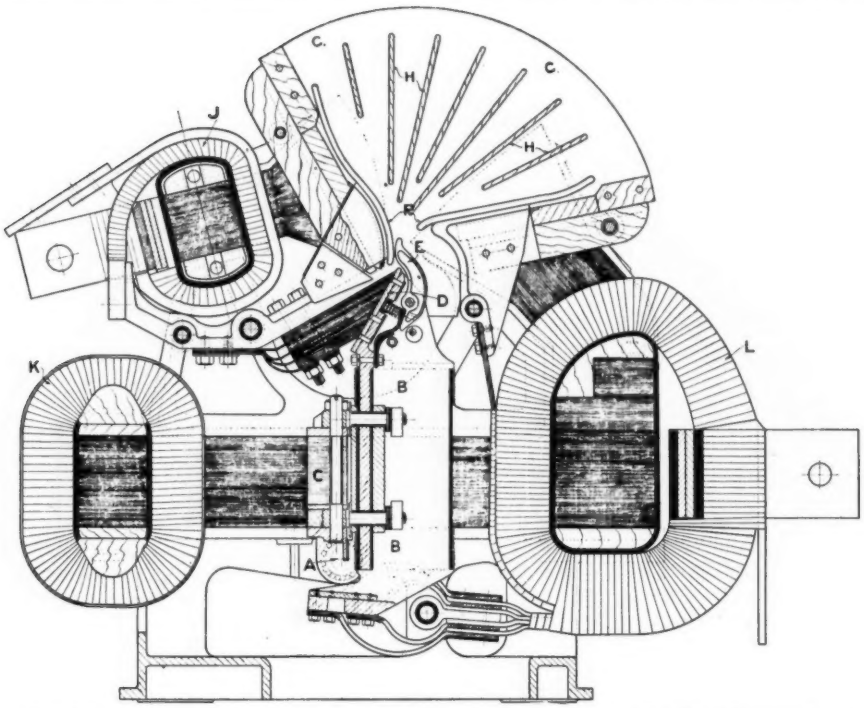
(5) Tripping value not greatly affected by fluctuations in line voltage.

(6) Rupture of arc effected by a specially designed magnetic field of adequate intensity and distribution.

(7) Blow-out rendered effective by special devices for neutralising the influence of conducting vapours and ionised gases.

(8) Reliability and absence of wear by reason of few moving parts.

As the moving portion is unrestrained by any springs, the opening forces are negligible when



A—Ball Bearings for
B—Moving Arm carrying
C—Laminated Armature, and
D—Contact Plate.
E—Arc Transfer Contact.
F—Arcing Horns.
G—Arc Chute.
H—Arc Dissipating Fins.
J—Auxiliary Blow-out Coil.
K—Shunt Closing Magnet.
L—Series Opening Magnet.

FIG. 2

the breaker is in the open position, and hence the force required to close it is quite small.

A very high speed of opening has been achieved without the use of pull-off springs, catches or triggers such as are found in some breakers to which the term " magnetic " is applied. This Company's breaker is rightly described as of the Magnetic Type, since the closing and opening movements are effected solely by magnetic forces. Springs, catches and similar mechanical auxiliaries inevitably introduce additional inertia and friction, which tend to set a limit to the speed of opening; at the same time, their use calls for a larger closing force, and consequently either a larger opening force or the use of auxiliary apparatus for reducing automatically the strength of the closing force.

Under practical operating conditions, the " English Electric " breaker exhibits the valuable characteristic that its tripping value is not greatly affected by a fall in line voltage, such as occurs frequently though transiently on traction systems. Consequently the breaker remains closed in many cases where earlier types would operate unnecessarily.

In view of the very heavy service to which a breaker of this kind is subjected, the mechanical design of all the parts has been made extremely robust, and it is satisfactory to record that breakers which have been in service for several years operating eight or ten times daily, have required little or no attention, beyond the adjustment of the auxiliary contact.

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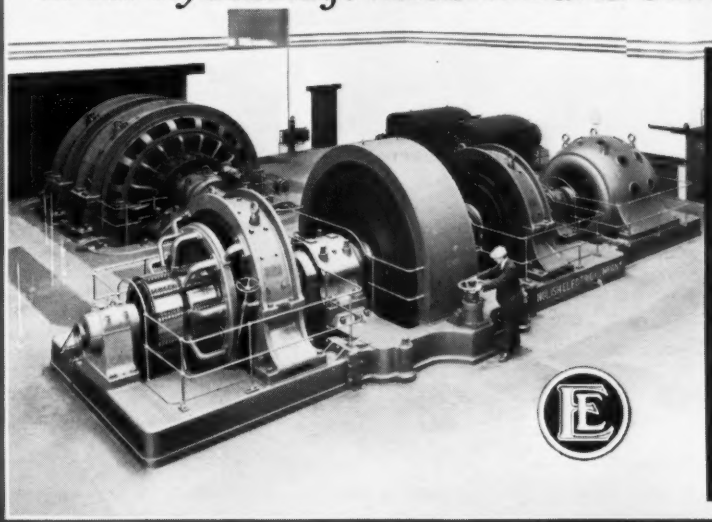

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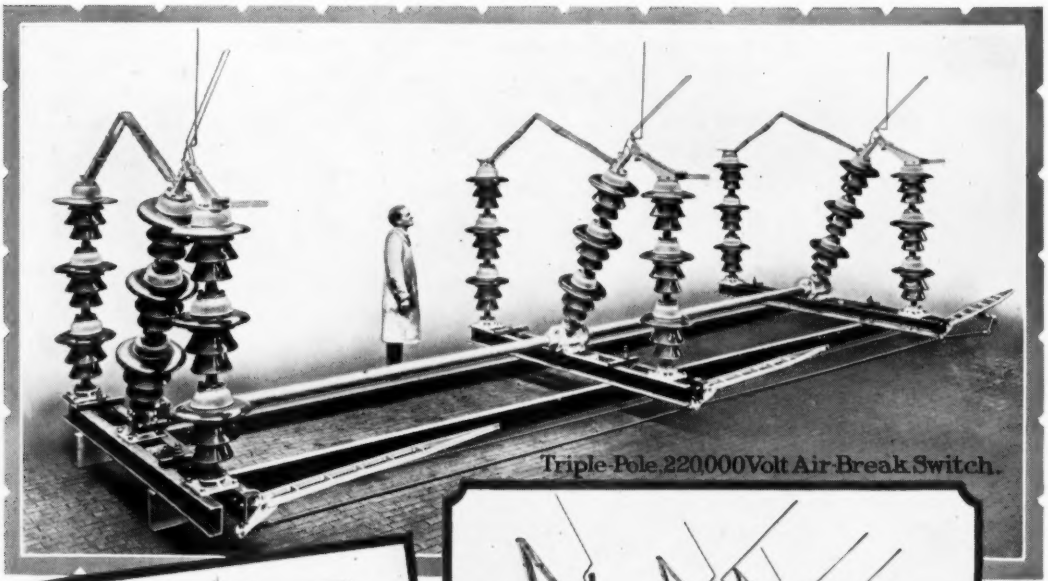

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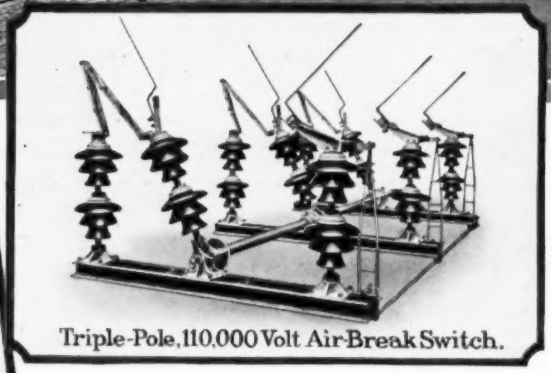

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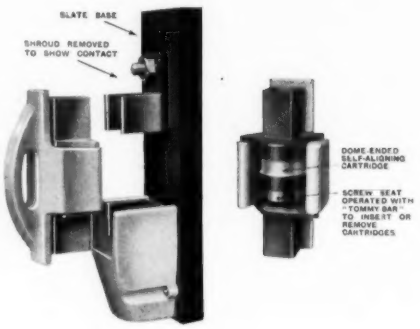
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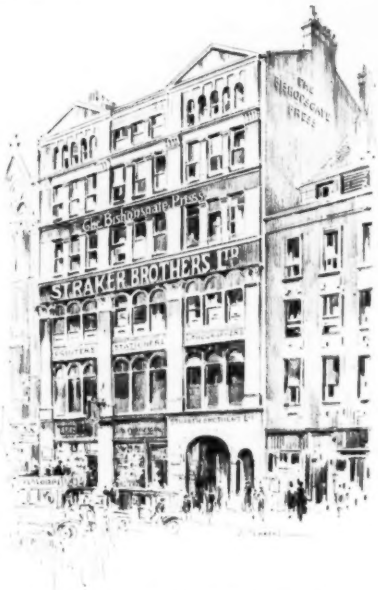

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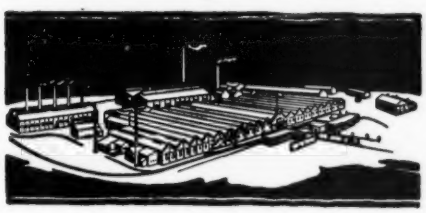

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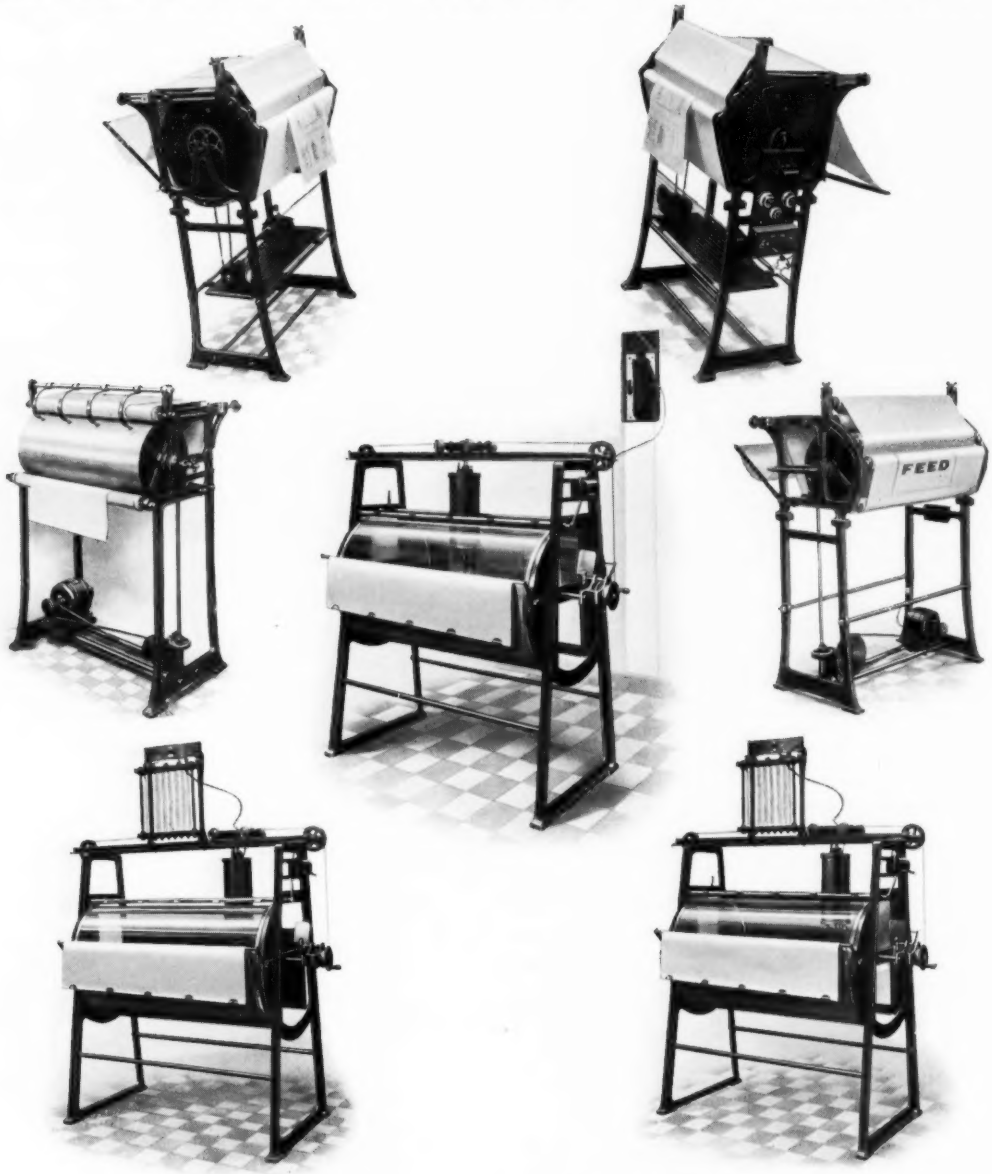

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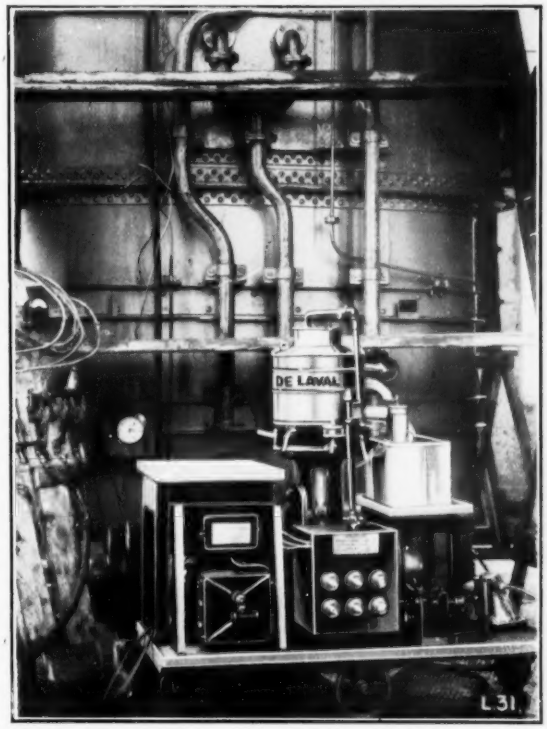

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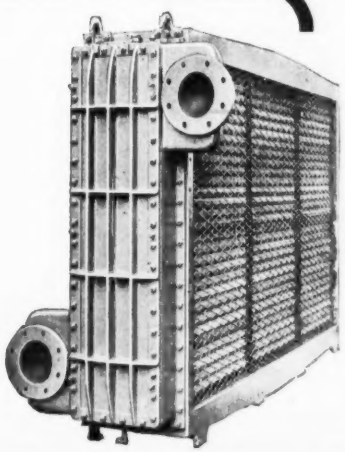

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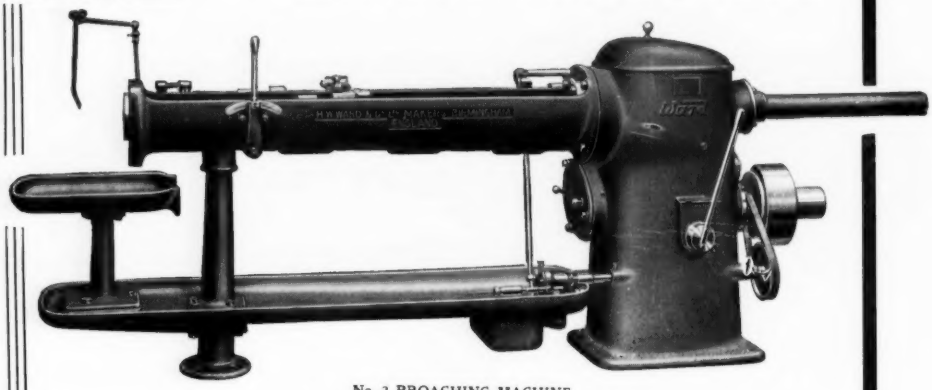

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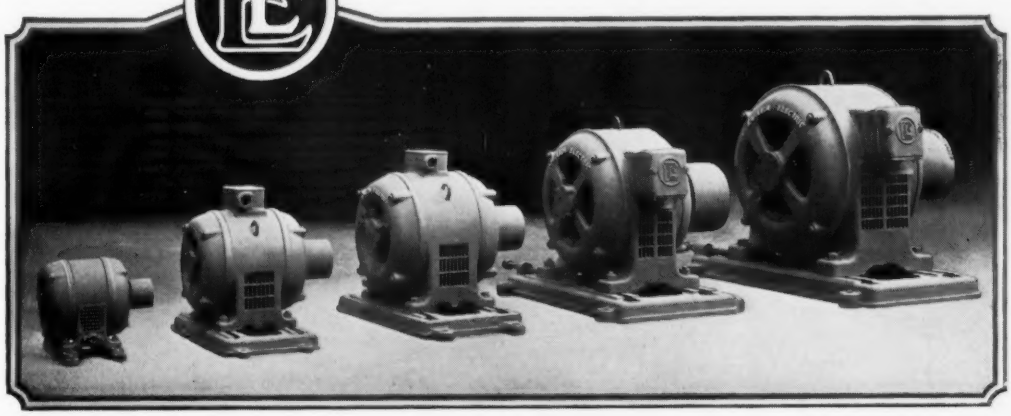

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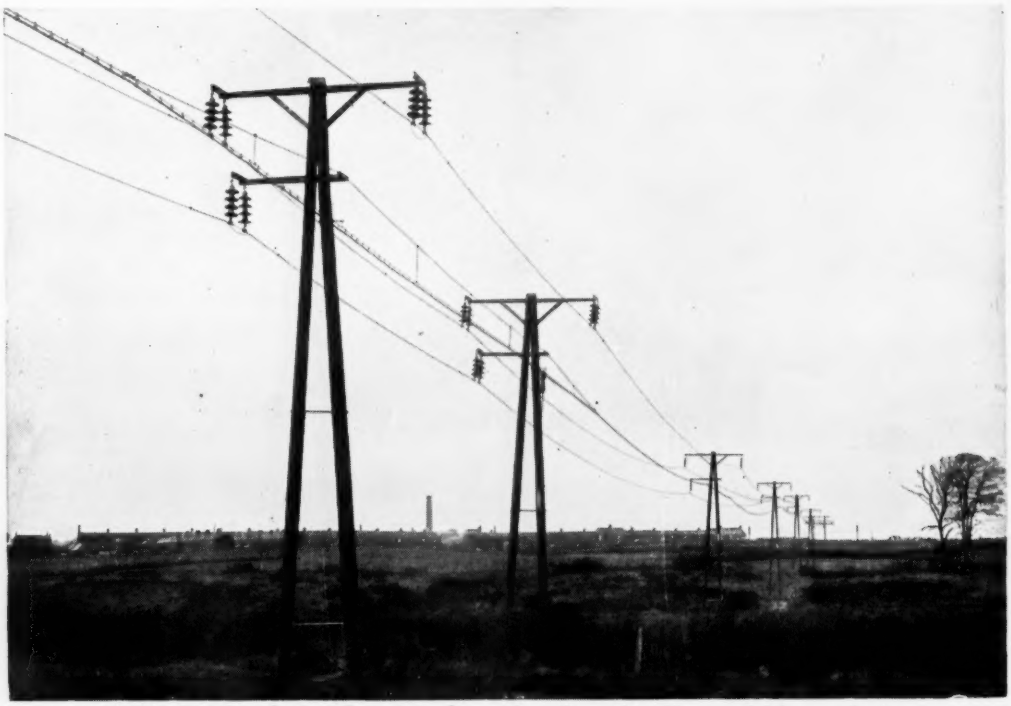

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